BACKSCATTERING OF SPECTRAL IRRADIANCE BY BUBBLES

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LONG-TERM GOALS

Our work is focused towards the analysis of the scattering properties of bubbles in the upper ocean, and their effect on the hyperspectral reflectance of the sea, both as a result of natural bubble introduction (e.g. breaking waves) and as a result of man-made injections (e.g. ship wakes).

SCIENTIFIC OBJECTIVES

We are attempting to address the following hypotheses: First, that organic coatings on bubbles significantly amplify the backscattering, but not the forward scattering coefficients on a bubble-specific basis; second, that natural bubble populations in the upper ocean are a dominant source of backscattering of hyperspectral irradiance and a less important source of forward scattering; and finally, that injection of bubbles in the upper ocean enhances the reflectance of the sea in the visible wavelengths, that the spectrum is shifted towards the green, and that the influence of enhanced bubble populations will violate the usual assumption that the ocean is black in the near infrared, hence complicating atmospheric correction for remote hyperspectral observations.

APPROACH

The work is a combination of theoretical development, development of new instrumentation and new methods to test the hypotheses, and observational efforts at sea. The organization of the work is such that the first year (1999) is focused on instrument development and testing, and laboratory measurements with simulated bubble populations. The second and third year are focused on field efforts to test the hypotheses under natural conditions.

WORK COMPLETED

Work started in January, 1999.

Theoretical Development: We have analyzed in great detail the volume scattering function for both coated and uncoated bubbles of various size distributions using Mie Theory. The resulting VSF's have been introduced into HydroLight, and the effect of bubbles and bubble injection on irradiance reflectance, diffuse attenuation, and the radiance distribution analyzed.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
30 SEP 1999		**00-00-1999 to 00-00-1999**

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Backscattering of Spectral Irradiance by Bubbles	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Satlantic, Inc.,Richmond Terminal, Pier 9, 3295 Barrington Street,Halifax, Nova Scotia, Canada B3K 5X8,**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**4**	

Laboratory Bubble Generator: We have completed, tested, and validated a new device for the production of bubbles, including very small bubble populations (10 microns) in the laboratory.

Optical Determination of Bubble Size Distribution: We have developed, tested and verified a new photographic imaging technique for the measurement of bubble populations in the laboratory which extends the previous methods to small size.

Acoustic Determination of Bubble Size Distribution: We have developed, tested and verified a new high frequency (megahertz) acoustic probe for the measurement of bubble populations.

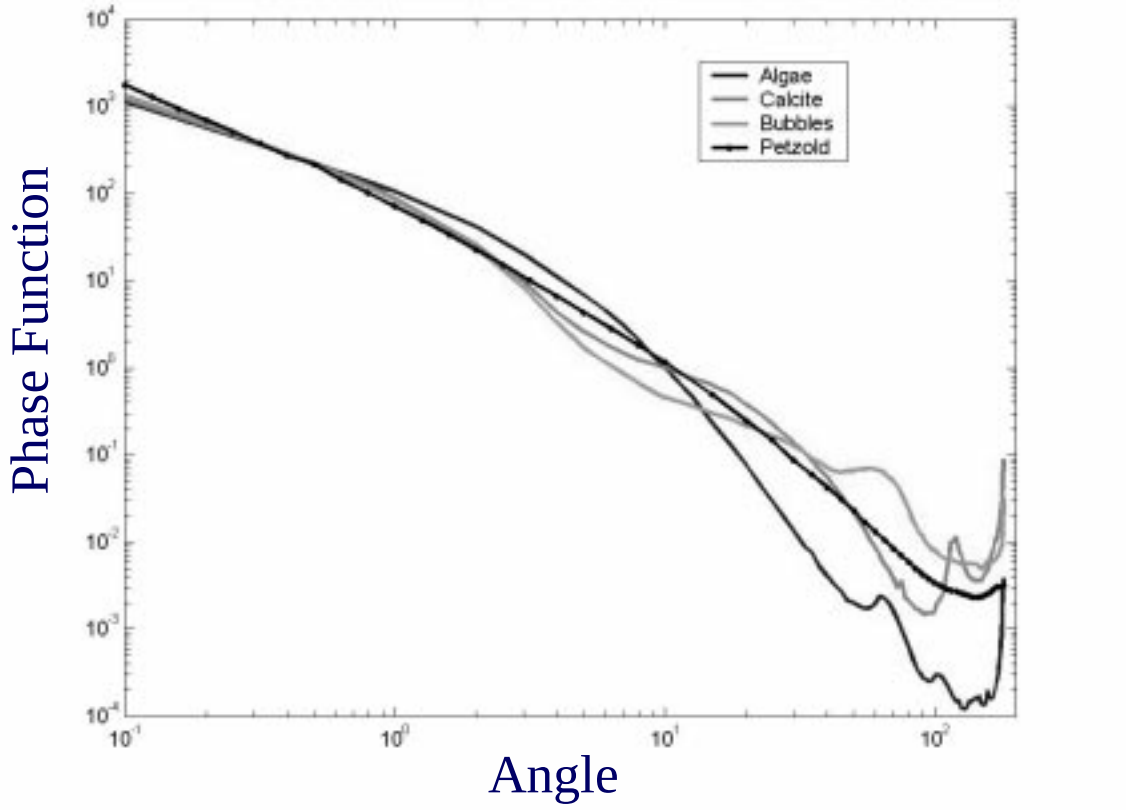
Hyperspectral Reflectance of Bubbles: We have completed a preliminary field effort in the Equatorial Pacific to examine the effect of bubble injection on hyperspectral reflectance using a new buoy for the measurement of upwelling radiance and downwelling irradiance over the spectral band 380-800 nm with 3 nm resolution.

RESULTS

Results are preliminary given that the program is in an early phase.

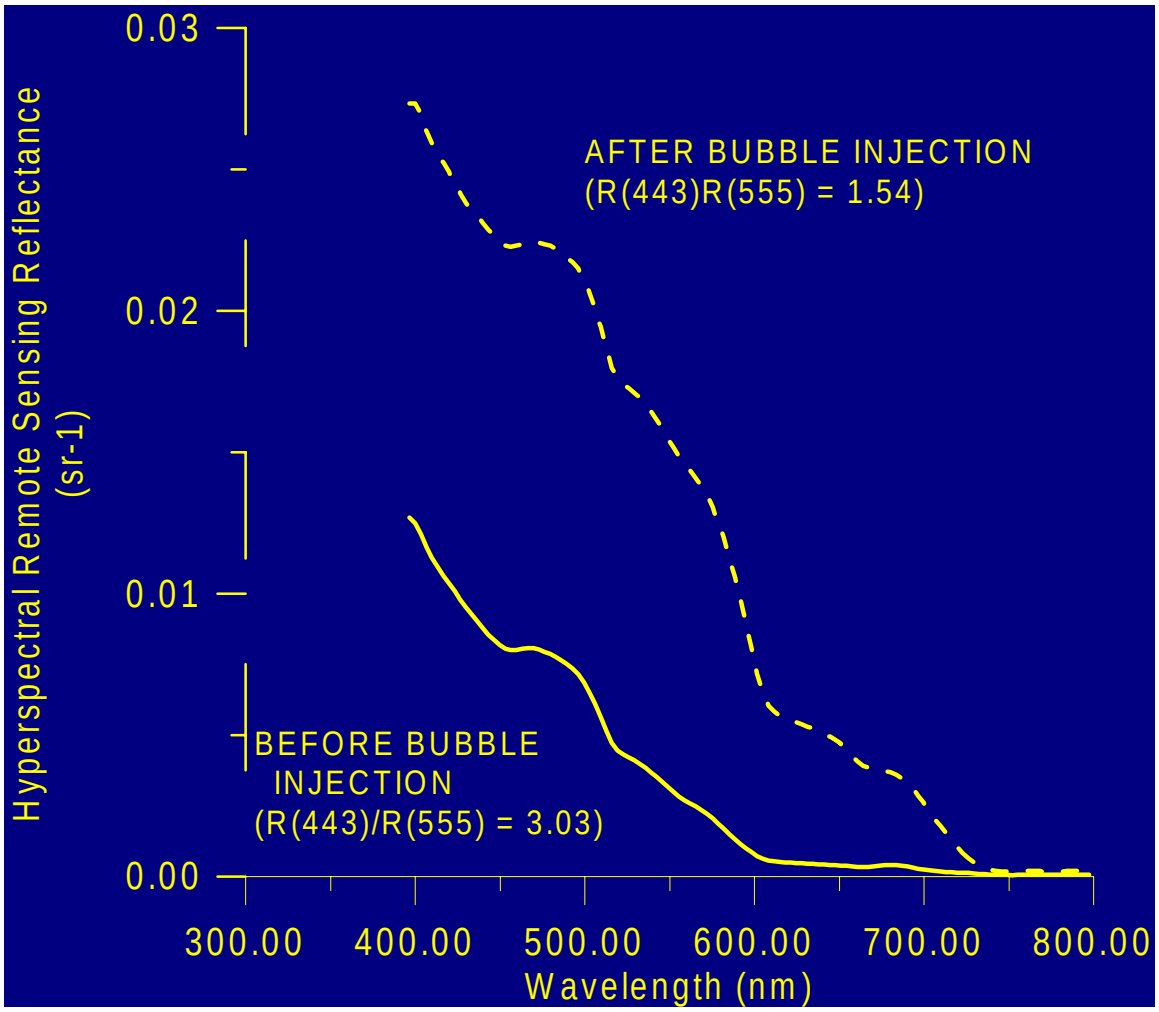
From a theoretical perspective, bubbles contribute strongly to scatterance in the backward direction, and less in the forward direction. Notable features of the VSF are a broad maximum due to total Fresnel reflectance, and a much higher scattering in the backward direction relative to algae (Figure 1).

Figure 1. Volume scattering function for bubble population relative to other scattering functions.



Results from the field deployment confirm theoretical predictions (Zhang et al. 1998): Bubble injections enhance the backscatter across visible and near-IR bands, and shift the spectrum towards the green (Figure 2).

Figure 2. Changes in hyperspectral reflectance after ship-induced bubble injection.



IMPACT/APPLICATIONS

The work has only started, and few impacts are evident at present, other than a large number of requests for information on bubble scatterance. Applications include the determination of hyperspectral reflectance properties in both open ocean and near-shore environments for sensor and weapon system evaluation, and the detection of wake signatures from remote observation.

TRANSITIONS

There are no transitions to date at this early stage.

RELATED PROJECTS

1) ONR Contract N0001496C0118 provides support to Lewis and Cullen to examine the fundamental aspects of phytoplankton influence on ocean optical properties, and for the development, use and testing of optical instruments for the evaluation of attenuation in coastal waters.

2) A project supported by the Canadian Space Agency which focuses on development of hyperspectral libraries of vessel reflectance, and statistical analysis techniques for vessel detection and classification, is complementary to this work.

REFERENCES

Zhang, X.., M.R. Lewis and B.Johnson. 1998. The role of bubbles in the scattering of light in the ocean. *Applied Optics,* 37: 6525-6536.

PUBLICATIONS

There are no publications to date on this work as it has just started.